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HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: III.

The Effects of CRT Display Size and Luminance on Dark Adaptation of Helicopter Pilots

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Previous research has indicated that pilots may be able to successfully use a television display of low luminance level as an aid to nighttime nap-of-the-earth helicopter flight. This experiment was conducted to assess the effects of display luminance level and display size on pilots' visual dark adaptation. Brightness matches made by 12 Army helicopter pilots were used to determine the magnitude of the dark-adaptation loss that resulted from viewing a 13-cm and a 26-cm CRT display at relatively bright and dim luminance

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20. levels. In the procedure used, one eye was light adapted to the CRT panel display while the other eye remained dark adapted. Then, while the pilots viewed a simulated windscreen display, the luminance setting for the dark-adapted eye was adjusted independently until the display appeared equally bright to both eyes. Windscreen display luminance for the previously light-adapted eye remained fixed at a highlight brightness of 0.01 footlambert (equivalent to full-moon illumination). The larger display was judged to produce the greater dark-adaptation loss, even though the larger display could be successfully used at a lower luminance level. This result might have been due to the greater involvement of the peripheral rod retinal receptor cells when pilots made judgments following exposure to the larger light-adapting display. In such a case, selective attenuation of the blue end of the spectral energy output from the CRT phosphor could reduce the magnitude of the light-adaptation effect. Under full-moon conditions, windscreen viewing within 1 second after light adaptation to a dim 26-cm television display showed a 67% loss in the apparent brightness of the windscreen display. This is equivalent to flying under one-third full-moon conditions. For a 13-cm panel display, the loss was only about half as great. The results also showed that even with a relatively bright display, almost complete recovery from light adaptation occurred within 2 minutes, for windscreen viewing under full-moon illumination.

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HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: III.
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FOREWORD

This is the final report in a series of three reports that describe research efforts to determine the behavioral requirements for an electro-optical display system for night nap-of-the-earth (NOE) helicopter flight. The two previous reports, TR-441 and TR-442, reported the results of experiments designed to determine the effects of display size, system gamma function, and terrain overflown on display luminance levels required for night NOE flight. The experiment reported here explores the effects of display size and luminance levels on the dark-adaptation function of pilots who view such displays.

The current report is the result of an in-house research effort begun by Dr. Aaron Hyman in response to Army Project 2Q162722A765 and is responsive to Human Resource Need 77-311 for the Deputy Chief of Staff for Plans and Operations.

JOSEPH ZEIDNER
Technical Director

HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: III. THE EFFECTS OF CRT DISPLAY SIZE AND LUMINANCE ON DARK ADAPTATION OF HELICOPTER PILOTS

BRIEF

Requirement:

Previous research has indicated that pilots may be able to successfully use CRT displays as aids to night nap-of-the-earth (NOE) flight when those displays are set for luminance levels in the mesopic range (e.g., with highlight luminance from 0.01 to 0.10 footlambert). However, before display requirements can be specified for a low-light television system to aid NOE night flying, the effects of cockpit CRT luminance levels on pilots' dark adaptation need to be determined.

Procedure:

After differentially light adapting their eyes, while viewing CRT displays of two different sizes and two luminance levels, 12 Army helicopter pilots made brightness matches as they looked at a windscreen display simulating full-moon illumination conditions. These brightness matches were used to determine the degree of dark-adaptation loss that resulted from viewing a television display set at different luminance levels and to obtain an approximate measure of the time necessary for a pilot to recover from light adaptation to these different luminance levels.

Findings:

As has been found in previous research, pilots judged that they could effectively use a 26-cm CRT display at lower luminance levels than a 13-cm display. However, the brightness-matching portion of this experiment shows that statistically there is a significantly greater dark-adaptation loss with the 26-cm display at this lower luminance level than with a 13-cm display. This might have been due to the greater involvement of the peripheral rod retinal receptor cells when pilots made judgments following exposure to the larger light-adapting display. In such a case, selective attenuation of the blue end of the spectral energy output from the CRT phosphor could reduce the magnitude of the light-adaptation effect. Under full-moon conditions, windscreen viewing within 1 second after light adaptation to a dim 26-cm television display showed a 67% loss in the apparent brightness of the windscreen display. This is equivalent to flying under one-third full-moon conditions. For a 13-cm dim panel display, the loss was only about half as great. Results also showed that even with a relatively bright display, almost complete recovery from light adaptation occurred within 2 minutes, for windscreen viewing under full-moon illumination.

Utilization of Findings:

Viewing an adequately dim CRT panel display subjects the pilots to an acceptably small dark adaptation loss when transitioning to viewing through the windscreen under full-moon illumination. However, the amount of dark-adaptation loss is greater at lower levels of illumination (e.g., starlight). It appears highly desirable that pilots be provided with a luminance control having an extended range of adjustability in the dim region, so that the panel CRT display can be set to suit the individual's sensitivity. This will permit faster transition from panel viewing to windscreen viewing during night flying.

HELICOPTER ELECTRO-OPTICAL SYSTEM DISPLAY REQUIREMENTS: III. THE EFFECTS OF CRT DISPLAY SIZE AND LUMINANCE ON DARK ADAPTATION OF HELICOPTER PILOTS

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INTRODUCTION

The experiment reported here is part of a larger research effort directed toward specification of display parameters for a low-light-level television (LLLTV) system used as a visual aid to night nap-of-the-earth (NOE) flight. See Hyman, Johnson, and Gade (1980) for an overview of this effort. During nighttime flight, it is important that the pilot maintain adequate visual adaptation to the dark. This is particularly true when the aviator is flying at NOE altitudes. A pilot using an LLLTV system as a visual aid, or any other display presenting information on a cathode ray tube (CRT), must be aware of the potential for degradation of dark adaptation if the display is too bright. It may become necessary for the pilot to switch quickly to windscreen viewing (e.g., in case of system failure). Thus the cockpit display should be operated at a sufficiently low luminance level to minimize its detrimental effect on a pilot's dark adaptation while permitting adequate form perception. In a previous study (Hyman et al., 1980), pilots felt that they could fly safely at NOE altitudes with display luminance in the mesopic range. The effects of such luminance levels on dark adaptation were determined in this experiment.

METHODS

Participants

The participants were 12 rated Army helicopter pilots who volunteered to serve in this experiment. All pilots had normal or corrected normal vision.

Apparatus

This experiment was conducted using the Army Research Institute for the Behavioral and Social Sciences (ARI) NOE visual flight simulation facility described as Configuration II in Hyman et al. (1980). The pilots viewed a televised simulated windscreen display presented on a black-and-white monitor (CONRAC Model RQA 17)[1] with its luminance set to represent full moon scene illumination, i.e., with highlight luminance set at 0.01 footlambert (fL). The light from the left and right half-fields of this display was polarized orthogonally. Each pilot viewed the display through goggles rigidly attached to a viewing hood. The left goggle lens was a polaroid filter oriented to be uncrossed for the left half-field of the windscreen display and crossed for the right half-field. The right goggle lens consisted of two polaroid filters. One was fixed, and oriented to be uncrossed for the right half-field and, therefore, crossed for the left half-field. The other filter could be rotated. By changing its angular position, the subject could set the luminance of the

[1]Commercial designations are used only for accuracy of reporting and do not imply recommendation by the Army or the Army Research Institute.

right half-field (seen only by the right eye) so it matched in apparent brightness the left half-field (seen only by the left eye). The position of the rotatable polaroid filter was monitored electronically at the experimenter's station. In a panel CRT display placed below the windscreen display, stimulus material was also shown in raster television format on either a 13-cm CRT monitor (GBC Model MV-5) or a 26-cm CRT monitor (SONY Model VO-1800). This stimulus material, which originated from videotape, was presented simultaneously in the windscreen (i.e., heads-up) view and on the lower panel (i.e., heads-down) display. The panel display was also fitted with a fixed and rotating polaroid filter system that permitted adjustment of its luminance. The position of the rotating filter on the display was also monitored electronically at the experimenter's station.

Procedure

The pilot was blindfolded for 15 minutes prior to the beginning of data collection, to obtain good dark adaptation of the cone retinal receptors (the visual receptors required for high-resolution vision). During the dark-adaptation period, the experimental procedures were described to the participant. Throughout the experimental session, the pilot remained seated in a light- and sound-attenuating booth. An intercom system was used to maintain continuous voice communication between the pilot and experimenter.

In the cross-adaptation technique employed, the participant viewed with the left eye an NOE flight presentation on either a 13-cm or a 26-cm heads-down display for 1 minute. During this time, the pilot's right eye was occluded, so that only the left eye was light adapted to the panel display. After this light-adaptation period, the participant immediately shifted viewing to the windscreen display and adjusted the rotatable polaroid filter in the right goggle lens so that the right half-field would appear to match the brightness of the left half-field (which now appeared subjectively dimmer because of the previous light adaptation). The pilot was instructed to make this adjustment as quickly as possible, since dark adaptation begins rapidly. These adjustments were accomplished by all participants within 5 to 10 seconds. Once the adjustment was made, the pilot was given another minute of left-eye light adaptation, followed by a brightness adjustment. This procedure continued until no further adjustments were required, i.e., the two half-fields of the windscreen display matched in brightness immediately after termination of the light-adaptation period. This state was usually attained in not more than four adaptation cycles.

Each pilot made brightness matches after light adapting to a panel display of 0.20 fL highlight luminance (identified in this study as the "bright" display), and after light adapting to a display selected by the pilot as the dimmest with which safe NOE flight could be accomplished (identified in this study as the "dim" display). A given pilot was exposed to either a 13-cm or a 26-cm panel display, but all pilots were light adapted to both the bright and dim luminance setting for the display they viewed; adaptation was always to the bright display first. The pilot was given 5 minutes for adjusting the panel display to the preferred dim level and light adapting to that level. After determining the initial brightness matches, each pilot was asked at 1-minute intervals to observe the windscreen display (with half-fields set for equal luminance) and indicate if the two fields appeared matched. Thus an approximate measure of recovery time was obtained.

RESULTS AND DISCUSSION

For each pilot, the matching luminance setting (in fL) for the right half-field of the windscreen display after light adapting the left eye constituted the dependent measure. This measure reflects the after-effect of light adaptation to the heads-down or panel CRT display. For example, suppose the pilot sets the right half-field of the windscreen display to match the left half-field at a highlight luminance of 0.001 fL. This means that the full moonlight windscreen display (having a highlight luminance of 0.01 fL) now appears to be only one-tenth as bright, or a 90% reduction in apparent brightness.

The mean brightness ratios obtained for the four CRT size/luminance conditions are given in Table 1. After light adapting by looking at the dim 26-cm panel display, the pilots judged the windscreen view at full moonlight luminance to be one-third as bright as they judged it before light adapting. This degradation was only about half as great following light adaptation to the dim 13-cm panel display. Degradation was always greater after light adaptation to the brighter displays.

Table 1

Mean Ratio of Luminance Setting for Right Eye to Luminance Setting for Left Eye[a]

Display size	Light adapting condition: Bright panel display	Dim panel display
13 cm	0.43	0.62
26 cm	0.17	0.33

Note. Highlight luminance of the bright panel display was set by the experimenter and maintained at 0.20 fL. Highlight luminance for the dim panel display was set by each pilot and therefore differed slightly among subjects. Their mean setting for the dim display was 0.033 fL. Highlight luminance for the simulated windscreen display was 0.01 fL.

[a]Only the left eye has been previously light adapted, and subjective brightness for the two eyes is matched upon immediate viewing of a moonlight scene through a simulated windscreen.

The matching luminance measures were analyzed for effects of display light adaptation (bright vs. dim) and display size (13 cm vs. 26 cm). Display light adaptation was a within-subject variable, and display size was a between-subject variable in a 2 x 2 ANOVA design. Light adaptation to the 26-cm heads-down display resulted in a lower apparent brightness of the moonlight heads-up display than did light adaptation to the 13-cm display (F (1,10) = 9.09, $p < .05$). Note, however, that the judgments made were luminance matches rather than clarity of detail.

Table 1 also shows that the brighter adapting displays caused a greater reduction in the apparent brightness of the moonlight windscreen display than did the dimmer adapting displays, as one might expect (F (1,10) = 7.88, $p < .05$). There were no significant interactions.

The retinal rod cells probably play the dominant role in luminance judgments, whereas the retinal cone cells play the dominant role in detail clarity (Brown, Graham, Leibowitz, & Ranken, 1953). The greater effect of the larger display size may be a reflection of the greater number of retinal rod cells involved. Since rod cells are more sensitive to the blue end of the visible spectrum than cone cells (Wald, 1945), it may be possible to decrease the amount of light adaptation caused by panel displays without decreasing the visibility of display detail by interposing a suitable optical filter (e.g., a yellow filter) over the phosphor face of the CRT.

The above analysis is based on the pilot's bright versus dim adjustments; hence it was of interest to determine whether or not the settings for the dim panel display were reliably lower than the settings for the bright panel display. The highlight luminance of the mean dim setting for all 12 pilots was 0.033 fL. This was tested against a hypothesized population mean of 0.20 fL for the setting of the bright panel display, by means of a t test. The dim settings were significantly lower than the bright settings (t (11) = 27.83, $p < .001$). In an additional analysis of the dim settings, the difference between mean highlight luminance settings for the 13-cm CRT display (0.045 fL) and 26-cm CRT display (0.019 fL) was found to be marginally significant (t (10) = 2.21, $p < .10$).

During readaptation, all pilots indicated that at moonlight levels the two half-fields of the windscreen display appeared equal in brightness within 2 minutes. This was true after light adaptation to both bright and dim panel displays.

CONCLUSIONS

The results of the present research indicate that pilots can utilize CRT displays of sufficiently low highlight luminance levels to avoid serious detrimental effects on dark adaptation when flying under moonlight conditions. Pilots selected display luminance settings in the mesopic range near the limits of cone vision, with the mean highlight luminance for the 26-cm display set lower than that for the 13-cm display. At these relatively low luminance levels, detrimental effects on dark adaptation are evident but minimal.

Within 1 second after switching to heads-up viewing, previous light adaptation to a dim 13-cm heads-down display was judged to have caused a 38% reduction in the apparent brightness of the moonlight windscreen display. For a dim 26-cm display, light adaptation caused a 67% reduction in apparent brightness. Thus, even though the 26-cm display was used at a lower highlight luminance level than the 13-cm display, the 26-cm display produced a more pronounced light adaptation effect. This might have been due to the greater number of retinal rod cells illuminated when viewing the 26-cm display. Selective reduction of rod cell light adaptation by attenuating (through suitable optical filters) the blue end of the visible spectral radiation emitted by the CRT phosphor may help to reduce this effect (Wald, 1945). Complete recovery to moonlight level dark adaptation occurred in less than 2 minutes with both display sizes under the dim condition. Although the initial decrement in dark adaptation was greater with the brighter display used in this experiment, complete recovery to moonlight level dark adaptation occurred within 2 minutes.

Complex displays were used in this experiment. The findings, nevertheless, are consistent with those obtained in earlier psychophysical experiments with simpler displays (Baker, 1953, 1963, 1973; Crawford, 1947). These earlier experiments showed that a large portion of recovery from light adaptation occurs within a fraction of a second for a threshold task.

Since individual pilots may vary in their requirements for display luminance, it appears to be wise to provide them with a luminance control having an extended range in the dim region, so they can readily set their panel display at the needed minimum luminance level.

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